Search for new physics in top events with the DØ detector

Isabelle Ripp-Baudot[1] [a]

IPHC, Université Louis Pasteur, CNRS/IN2P3, Strasbourg, France

Abstract. This review is focused on the search for new processes, performed with top quark events in DØ. It presents four updated or new DØ results. The two first analyses deal with top production properties: they search for a new heavy resonance decaying to $t\bar{t}$. The two last results concern top decay properties: the measurement of the W helicity as a probe of the tWb coupling structure, and the top quark branching ratio to Wb. Neither of these measurements reveal any deviation with respect to the standard model predictions.

PACS. 14.65.Ha Properties of the top quark – 12.60.-i Models beyond the standard model

1 Introduction

This review is focused on the search for new physics performed with top quark events in DØ. It presents four updated or new DØ results. The two first analyses deal with top production properties: they search for a new heavy resonance decaying to $t\bar{t}$. The two last results concern top decay properties: the measurement of the W helicity as a probe of the tWb coupling structure, and the top quark branching ratio to Wb.

The Tevatron $p\bar{p}$ collider at Fermilab operates with a center-of-mass energy of 1.96 TeV. Beams are colliding in two points instrumented by the CDF and the DØ multipurpose detectors. Since 2001 the Tevatron is in its second run and, thanks to very good performances, it has already delivered more than 3 fb^{-1} to each experiment in 2007. The results included in this review are those based on about 1 fb^{-1} of data. Up to 4 to 8 fb^{-1} are expected per experiment until the smooth running of the LHC, i.e. at least 50 times as much top as available at the end of the Run I which lead to the top discovery.

Up to now the top quark is observed experimentally via $t\bar{t}$ pair production through the strong interaction. Electroweak production of a single top is also possible but with a smaller cross-section and a larger background, so that the first evidence of this process has been shown only recently by DØ [1]. Single top events are also sensitive to new physics but this channel suffers from its low statistics. All analyses presented in the following are therefore performed with $t\bar{t}$ events.

Due to its high mass, the top quark decays to a real W and a b quark before hadronizing. Measurements are grouped according to the W decay channel. The more leptons present in the final state, the smaller the background but also the lower the statistics. Therefore the considered channel will generally be the lepton+jets one, accounting for about 30 % of the $t\bar{t}$ final states. The background for this channel can be split into two components: on the one hand a physical background originating from processes showing a similar final state, among which the dominant one is the W+jets production; on the other hand an instrumental background coming from the multijet production where a jet mimics the isolated lepton. The background is efficiently reduced by requiring one or two jets to be b-tagged, using track impact parameters and displaced vertices information combined in a neural network algorithm [2].

2 Top production properties

2.1 New resonance direct search

DØ has performed a model independant search for a new heavy neutral resonance decaying to $t\bar{t}$ [3], generically referred to as Z'. The $Z' \to t\bar{t}$ channel is of particular interest in models with a leptophobic Z' decaying dominantly to quarks. The width of this Z' boson is assumed to be narrow, that is to say small with respect to the detector resolution, so that the resonance should be visible in the $t\bar{t}$ invariant mass distribution.

Several methods have been evaluated to reconstruct this invariant mass. The chosen one combines the charged lepton momentum, the four leading jets momenta and the inferred ν momentum. The $t\bar{t}$ invariant mass distribution is used to perform a binned likelihood fit of the signal and background expectations compared to data.

No evidence for a $t\bar{t}$ narrow resonance has been found. Upper limits on the heavy resonance production cross-section time the branching ratio to $t\bar{t}$ are extracted over all the range of resonance masses. They

[a] on behalf of the DØ collaboration

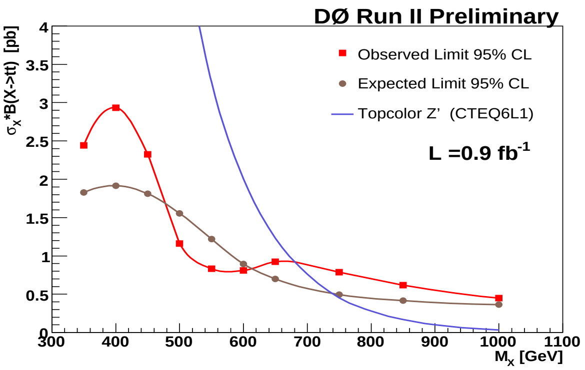

Fig. 1. Expected and observed upper limits on the heavy resonance production cross-section time the branching ratio to $t\bar{t}$ as a function of the resonance mass.

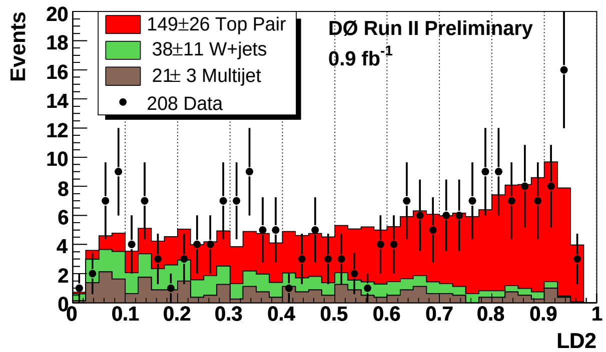

Fig. 2. Distribution of the multivariate discriminant function for the data (dots) and the model (histogram) for forward top quark events.

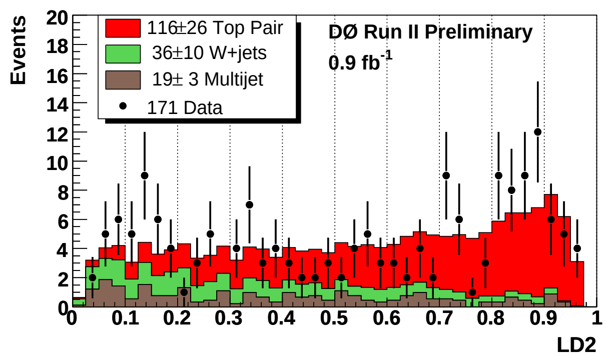

Fig. 3. Distribution of the multivariate discriminant function for the data (dots) and the model (histogram) for backward top quark events.

are shown in figure 1. Within a topcolor assisted technicolor model, the existence of a narrow leptophobic Z' decaying to $t\bar{t}$ is ruled out at the 95 % C.L. below 680 GeV/c^2.

2.2 Top forward-backward asymmetry

The measurement of the forward-backward asymmetry in the $t\bar{t}$ pair production at Tevatron is sensitive to new physics processes, as for example an alternative pair production via the decay of a new heavy neutral boson. This study does not need to assume anything about the resonance width, and thus it is complementary to the direct search of a narrow resonance presented in section 2.1. It is sensitive to any new process giving a $t\bar{t}$ final state with a large forward-backward aymmetry, as the standard model predicts only a small asymmetry in the $t\bar{t}$ pair production at Tevatron

This forward-backward asymmetry is measured in DØ from the signed difference between the t and the $\bar{t}$ rapidities. The acceptance may strongly shape the observed asymmetry, mostly through criteria imposed on the number of jets and on the jet momenta. The asymmetry is furthermore diluted by reconstruction effects such as misidentification of the lepton charge. In order to facilitate comparisons with theoretical calculations, the analysis is designed to have an acceptance which can be easily described at the particle level. Thus the obtained result is given for a given region of phase space, specific to this analysis, and uncorrected for reconstruction effects.

The measured asymmetry is [4] $A_{FB} = 12 \pm 8(\text{stat.})^{+1.1}_{-1.0}(\text{syst.})$ %, in good agreement with the standard model predictions. This measurement is obtained through a likelihood fit comparing the distribution of a multivariate function to templates for forward and backward top quark events. These distributions are shown in figures 2 and 3. The extracted upper limits on A_{FB} are translated into limits on the fraction of top-pair events produced via the decay of a heavy boson. The high measured asymmetry value does not yield yet useful limits on this production channel and it will be interesting to do this analysis with more statistics.

3 Top decay properties

3.1 Top-W-b coupling structure

In the standard model the charged weak current is described by a pure V-A structure. This fundamental property can be tested at the highest energy scale by measuring the W boson helicity in the top decay. The standard model predictions for the three helicity fractions, at the tree level and in the massless b quark approximation, are 30 % of left-handed W, 70 % of longitudinal W and no right-handed W (i.e. expected right-handed fraction $f_+ = 0$). These fractions are measured in DØ from the angular distribution of the top decay products. The considered angle is between the charged lepton direction in the W restframe and the W direction in the top restframe.

For this measurement only, both the lepton+jets and the dilepton channels are used. Events are selected in two steps. After a set of sequential cuts, a multivariate discriminant function is formed using both kinematical and b-tagging informations. The composition in signal and background of the selected can-

didates is obtained by fitting the distribution of this discriminant function. Then a cut on this multivariate discriminant variable further enriches the sample in $t\bar{t}$ signal. The reconstructed angle is estimated through a constrained fit. A binned likelihood compares this angle reconstructed in data to templates formed with different fractions of a non-standard V+A admixture to the weak current. The fraction of longitudinal W is fixed to its standard value of 0.7 during the fit. The obtained result for the fraction of right-handed W is [5] $f_+ = 0.017 \pm 0.048(\text{stat.}) \pm 0.047(\text{syst.})$, in good agreement with the standard model prediction. Figures 4 and 5 show the angular distribution for the data as well as for two simulations: the predicted sum of signal and background in the standard model and assuming a pure V+A structure.

The future plan for this analyses is to fit simultaneously both fractions of longitudinal and right-handed W, giving a model independant result.

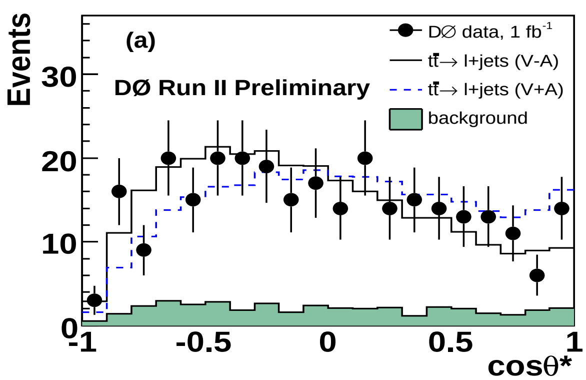

Fig. 4. Angular distribution for the lepton+jets data and for the predicted sum of signal and background in the standard model and assuming a pure V+A structure.

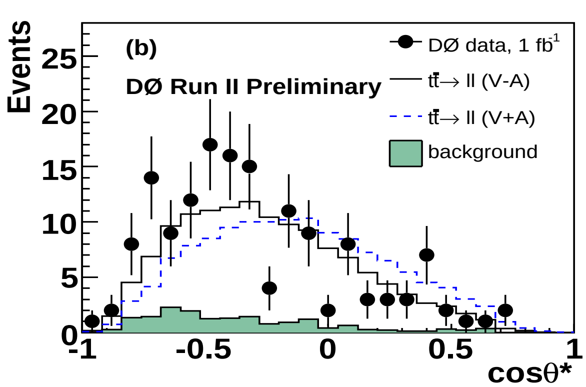

Fig. 5. Angular distribution for the dilepton data and for the predicted sum of signal and background in the standard model and assuming a pure V+A structure.

3.2 Top quark branching ratio

This measurement tests the branching ratio of the top quark to the b quark with respect to all other known down-type quarks. In the standard model we define the ratio $R = \mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$, where q refers to any known down-type quark. This ratio R can be expressed in terms of the corresponding CKM matrix elements. Once it is precisely measured it will provide a model independant measurement of the matrix element $|V_{tb}|$. A deviation of R from unity would indicate non-standard top decay. But to be sensitive to such effects at the Tevatron requires very good accuracy for this measurement, at the % level, and may need the combination of CDF and DØ results.

Experimentally R can be determined simultaneously with the pair-production cross-section $\sigma_{t\bar{t}}$ by classifying the $t\bar{t}$ selected candidates into events with 0, 1 and 2 b-tagged jets. A binned likelihood fit is performed which compares the observed number of events in these 3 bins with the prediction for signal and background. A discriminant function based on the kinematic properties of the $t\bar{t}$ events is used to further constrain the number of events without b-tagged jets. The dependance on R of the selection and the b-tagging efficiencies is taken into account when predicting the signal contribution in each bin. The values of the the ratio R and of the cross-section that maximize the 2-dimensional likelihood function are [6]

$R = 0.991^{+0.094}_{-0.085}(\text{stat.+syst.})$ and

$\sigma_{t\bar{t}} = 8.10^{+0.87}_{-0.82}(\text{stat.+syst.}) \pm 0.49(\text{lumi.})$ pb, they are illustrated in figure 6. These values are in good agreement with the standard model expectations of $R = 1$ and $\sigma_{t\bar{t}} = 6.8 \pm 0.6$ pb [7] for a top quark mass of 175 GeV/c^2. This measurement of R is by far the most precise up to now.

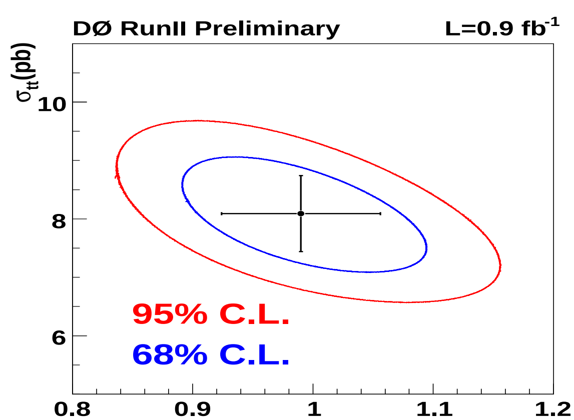

Fig. 6. Values of the simultaneously measured ratio R and cross-section $\sigma_{t\bar{t}}$ with the 1 and 2σ contours.

4 Conclusion

The top quark is the heaviest fundamental known particle and its study allows us to test the standard model at the highest energy scale available. The Tevatron has been up to now the unique place to study the top quark. With the Run II data we have entered a phase of precision measurements in the top sector. This precise characterization of the top quark aims at discovering hints of the physics laying beyond the standard model. In this review we have reported four analysis performed by DØ and looking for new processes occuring during the top production and the top decay. Neither of these measurements reveal any deviation with respect to the standard model predictions. Nethertheless they are still statistically limited and they will benefit from the expected increase of the luminosity in the next two years.

References

1. The DØ Collaboration (V.M. Abazov *et al.*), Phys.Rev.Lett. **98**, 181802 (2007).
2. T. Scanlon, Ph.D. thesis, University of London (2006). FERMILAB-THESIS-2006-43.
3. The DØ Collaboration (V.M. Abazov *et al.*), DØ-note 5443-CONF, july 2007, preliminary results for Summer conferences.
4. The DØ Collaboration (V.M. Abazov *et al.*), DØ-note 5393-CONF, july 2007, preliminary results for Summer conferences.
5. The DØ Collaboration (V.M. Abazov *et al.*), DØ-note 5431-CONF, july 2007, preliminary results for Summer conferences.
6. The DØ Collaboration (V.M. Abazov *et al.*), DØ-note 5437-CONF, july 2007, preliminary results for Summer conferences.
7. N. Kidonakis and R. Vogt, Phys.Rev.D **68**, 114014 (2003) and private communication.